with the author's compliments

DIVISION OF PATHOLOGY AND PHYSIOLOGY

BULLETIN NO.

REPORT OF WORK

OF THE

EXPERIMENT STATION

OF THE

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

IMPERIAL BUREAU
28 JUN. 1921
OF MYCOLOGY

Preliminary Notes on Root Disease of Sugar-Cane in Hawaii

BY L. LEWTON-BRAIN

HONOLULU, H. T.
1905

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DIVISION OF PATHOLOGY AND PHYSIOLOGY

BULLETIN NO. 2

REPORT OF WORK

OF THE

EXPERIMENT STATION

OF THE

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

Preliminary Notes on Root Disease of Sugar-Cane in Hawaii

BY L. LEWTON-BRAIN

1905

LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the Hawaiian Sugar Planters' Association, Honolulu, T. H.

Dear Sirs:—I herewith submit for publication as Bulletin No. 2 of the Division of Pathology and Physiology an article entitled "Preliminary Notes on Root Disease of Sugar Cane in Hawaii." This article has been prepared by Mr. L. Lewton-Brain, Assistant Director of this Division.

Yours very respectfully,

N. A. COBB,
Director, Division of Pathology and Physiology.

Honolulu, T. H., October 12, 1905.

FIG. 1. Two canes, from different stools, to show the effect of root disease on growth, from a photograph. These canes are of the same variety, and were taken from the same row, so that they were grown under identical conditions; they were between three and four months old. The cane on the right (*B*) is badly attacked by root disease, while that on the left (*A*) is only slightly attacked. (It was impossible to find a perfectly healthy cane for comparison.) See pages 10 and following.

PRELIMINARY NOTES ON ROOT DISEASE OF SUGAR-CANE IN HAWAII.

(With 12 Original Illustrations in the Text)

INTRODUCTION.

Root disease is very widely distributed in these islands; during the short time I have been here, specimens showing it have been received from several plantations on Oahu, Hawaii and Maui, and it would appear that the disease occurs, to a greater or less extent, in most of the sugar-producing districts of the group. It is by no means a new disease here; the characteristic symptoms of it have been observed for many years, although it is only recently that their real significance and importance has been generally realized.

A very similar root disease of cane is spread throughout the West Indies. In the island of Barbados alone, the loss in sugar and molasses caused by this disease in 1903 was estimated at nearly £100,000 ($480,000), the season of 1903 being extremely favorable to the spread of root disease. The West Indian root disease also occurs in Java, where it is known as the 'donkelan ziekte.'

In Hawaii, root disease is without doubt the most important of the fungoid diseases of the sugar-cane. It is largely owing to the fact that the Lahaina and Rose Bamboo varieties have proved, or have become, susceptible to root disease that it has become necessary to abandon them, in favor of the Yellow Caledonia variety, in many localities. So important and widespread is the disease that it has been considered advisable for me to prepare this preliminary bulletin, now, with the facts we have on hand, rather than wait until our investigations are complete, as these must necessarily be extended over a considerable period of time.

STRUCTURE AND FUNCTIONS OF SUGAR-CANE ROOT.

Before entering into an account of root disease itself, it may perhaps be advisable for me to describe, briefly, the structure of

the normal root of the cane; for, unless the various tissues of the root are known and also the part each plays in the life of the cane, it will be impossible to understand how a parasitic fungus, which attacks one part or another, influences the growth and development of the cane plant as a whole.

ORIGIN OF ROOTS.

In the first place the sugar-cane has no main root from which other roots develop by branching. As in all plants of the grass family (*Gramineae*), the roots of the cane arise adventitiously from the stem. At every joint (or node) of the stem a large number of small, clear points can be seen; below each of these are dormant rootlets, each of which, if given the proper conditions, of moisture, darkness and warmth, will develop into a root. The root system, then, of the cane is fibrous, consisting of a large number of perfectly independent roots all arising from the stem. These roots do branch, but to a very limited extent; moreover, the life of the individual roots is also limited; after a time they die and their loss is made good by the development of new roots from the underground and lower portions of the stem.

FIG. 2. Tip of sugar-cane root, showing root cap and position of root hairs. The circular black background in this figure is put in, in order to show up the delicate white root hairs. Magnified 1½ diameters.

Fig. 3 is a section through the apical part of this, going back as far as the root hairs, and is cut in the plane of the paper. Fig. 4 is cut through, across the long axis, in the region of the root hairs.

EXTERNAL FEATURES.

If some of the roots are allowed to develop in moist air, we get the appearance shown in Fig. 2. The root is for the most part pure white, but at the extreme tip it is of a dull yellowish or brownish colour; this brown part, as we shall see later, fits like a cap over the root tip and is, in fact, the root cap. In specimens exposed to light the root cap often assumes a pink or red colour, as do sometimes other parts of the root, due to the development of a red pigment in the superficial cells.

Some millimetres behind the tip are to be seen a number of very fine delicate hairs, the root hairs. When the root is growing in the earth, the root hairs grow very close to the small soil particles; their walls become somewhat gelatinous and fuse very

firmly on to the soil particles, so much so that in pulling a root out of the soil the root hairs are practically always broken and remain in the soil. The root hairs are thus in very close contact with the soil water, their walls are delicate and very permeable and it is through them that the water, with nitrates and other mineral salts in solution, passes from the soil into the plant. By watching carefully it is seen that, as the root grows forward, new root hairs are continually being developed in front, while those behind are as continually dying. So, as a root grows forward in the soil, its root hairs are continually coming in contact with fresh soil particles.

By careful measurements, the methods of which need not be described here, it is found that the growth in length of the root is confined to a very definite region. The region at the extreme tip does not elongate at all; elongation begins one or two millimetres behind the tip; it rises to a maximum a little further back, then sinks again until finally, in the region of the root hairs, there is no growth in length at all. The root hairs, then, as they develop, are not subjected to a continual dragging forward as they would be if they arose nearer the tip. As the growing region elongates, it pushes the root tip further and further into the soil.

STRUCTURE OF ROOT TIP.

These regions are brought out more clearly by examining a thin section, cut longitudinally through the middle of a root tip, under a low power of the microscope. Such a section, magnified 42 diameters, is shown in Fig. 3.

Starting at the tip, the first structure is the root cap (Fig. 3. *r.c.*) The outermost part of this is seen to be composed of loose, dead cells with brown walls. These cells are being constantly rubbed off, as the root pushes its way into the soil, and are as constantly being renewed from the living cells behind.

Covered over by the root cap is a mass of very delicate, thin-walled, closely packed cells forming the actual tip of the root (Fig. 3. *m.*). These cells are meristematic, that is to say, they are constantly in a state of active division. Fresh cells are thus continually being added, in front to the root cap and behind to the various tissues of the root. As these cells are cut

off behind, they commence to elongate and various stages in elongation can be seen in Fig. 3. The formation and growth of

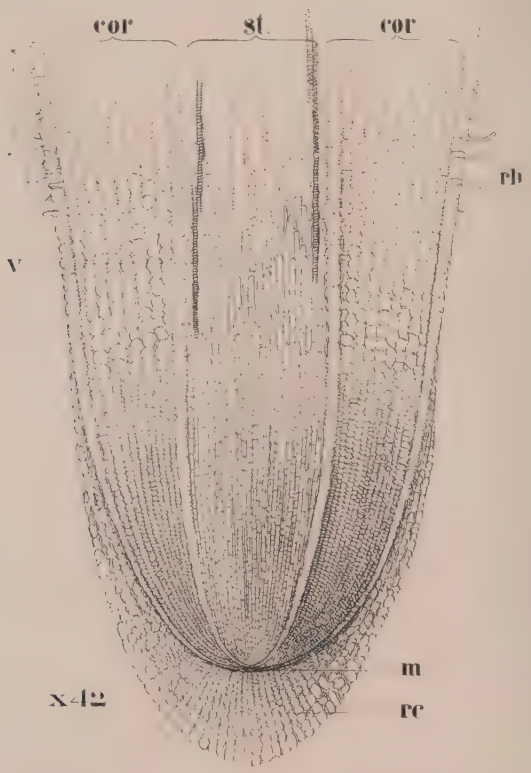

FIG. 3. Median longitudinal section of tip of root, showing root-cap (*r.c.*), meristem (*m*), piliferous layer with root hairs (*r. h.*), cortex (*cor.*), central cylinder (*st.*), with developing wood-vessels (*v.*) Magnified 42 diameters.

The root cap protects the meristem from injury, as the root pushes its way through the soil. The meristem is the region of cell division, and from it arise all the tissues of the root; note its thin-walled, small, closely packed cells, which are in an active state of division. The piliferous layer is the superficial covering layer of the root; a root hair is a simple outgrowth from one of its cells; the root hairs are the absorbing organs of the root. The woodvessels are the conducting elements of the plant, they carry the water absorbed by the root hairs up to the leaves; their walls become thickened, in various ways (spirally in the young ones shown), and woody.

these new cells behind the meristem, of course, forces this further

and further into the soil. Hence we see the importance of the root cap in protecting the delicate cells of the root tip or meristem from coming into contact with the soil. The importance of the meristem itself can also be recognized; it is the only part of the root where new cells are formed, consequently if the meristem be injured or destroyed all growth must cease.

Turning now to the growing region behind the meristem, we find, besides the elongation of individual cells, another process taking place. This is the fusion of separate cells. The cross walls between two cells, standing directly one above the other, become dissolved, and the cavities of the cells become continuous. Whole rows of cells take part in this process until we get long tubes formed, which connect above with similar structures formed in the same manner. These tubes are seen only in the central part of the root and are known as vessels (Fig. 3. *v.*). Later on their living contents disappear and then their walls become thickened and chemically changed.

Behind the growing region, we come to that part of the root where the cells, having attained their full length, begin to assume their permanent characters. The walls of some, notably of the vessels, thicken and change in various ways to fit them for their various functions. In this region, the root hairs are developed; they arise as simple, tubular outgrowths from the outermost layer of cells (Fig. 3. *r.h.*), and their walls are seen to be extremely thin and delicate. New ones are constantly being formed nearer the tip as fresh cells of the outer layer assume their permanent shape and form, and as constantly die away behind. After the root hairs are dead the outer layers of cells change their walls and become corky, so preventing the taking in of water in the region behind the root hairs, and protecting the inner tissues from injuries.

STRUCTURE AS SEEN IN TRANSVERSE SECTION.

After having seen the various tissues in longitudinal section and having traced their origin from the cells of the growing point, it will be well to examine their arrangement as seen in a section cut transversely through the root. Such a section, taken through the region of the root hairs, is figured, magnified 75 diameters, in Fig. 4. On the outside, we get again the special layer of cells, the piliferous layer, forming a kind of skin to the root, from which the root hairs are developed. The hairs (Fig. 4. *r. h.*) are seen again to be mere outgrowths from single cells.

After the hairs have fulfilled their uses, the walls of these cells become corky, and the cells no longer function in absorbing water but only as a protective layer.

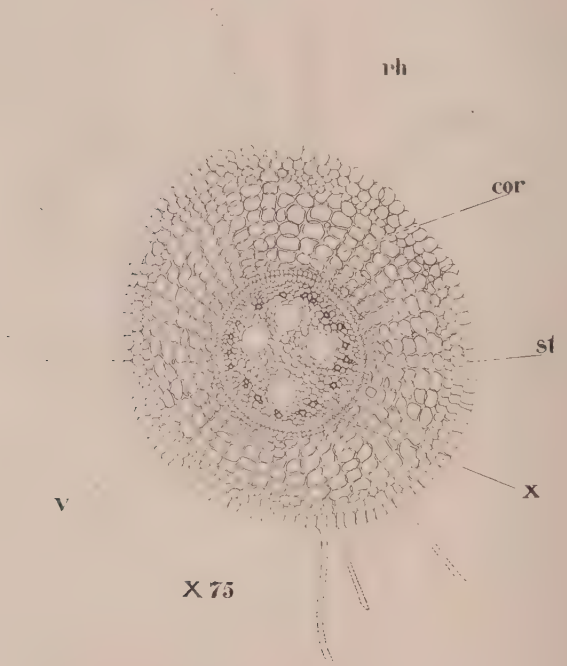

FIG. 4. Transverse section of root in region of root-hairs, showing piliferous layer with root-hairs (*r. h.*), cortex (*cor.*), central cylinder (*st.*) with first formed wood-vessels (*v.*) and developing larger vessels (*x.*). Magnified 75 diameters.

This section is taken across the part of the root corresponding to the top of Fig. 3. The two sections should be carefully compared, and the corresponding tissues in each made out. In this way a clear idea will be obtained of the relationships of the different parts of a young root.

Within this outer layer, are noticed two regions very definitely marked off from each other; these are an outer cortex (Fig. 4. *cor.*), and the inner central cylinder (Fig. 4. *st.*). Comparing with Fig. 3, it is noticeable that these two regions are to be distinguished right down to the growing point and have their origin in separate parts of the meristem. The cells of the outer part are uniform, thin-walled, living and loosely arranged. The ele-

ments of the central cylinder are more varied and generally are smaller than those of the cortex. Standing out from the rest are certain thick-walled, woody elements (Fig. 4. *v.*), which occur in a large number of small groups (in the specimen figured nineteen), arranged in a ring near the outer part of the central cylinder. These thick-walled elements are the vessels, which, as mentioned before, are really long pipes or tubes, formed by the fusion of several shorter elements. Within the ring of thick-walled vessels we see a smaller number of larger tubes (Fig 4. *x.*), cut across. These are also vessels which have not yet thickened their walls or become woody. These groups of vessels are really strands cut across; every vessel joins on above and below to other vessels, so that we get a continuous system of pipes, starting near the root hairs, and running the whole length of the root up to its origin in the stem. Not only so, but these strands of vessels become continuous with similar strands in the stem and these in turn join on to the strands in the leaves which are found in the ribs. Thus there is a continuous system of pipes, woody vessels, from the tips of the roots to those of the leaves. These wood vessels are the elements that conduct the water, with the contained food salts, from the roots to the leaves, where it is combined with carbon dioxide taken from the air and elaborated into sugar and other more complex organic substances.

FUNCTIONS OF THE ROOT.

The root system has two main functions; these are (1) the fixing and holding the plant firm in the soil, and (2) the taking in of water, with food salts in solution, from the soil and passing it up to the stem.

The sugar-cane has an enormous number of roots which spread in all directions into the soil. Each root has near its tip a large number of root hairs, each one of which practically fuses with the soil particles. It will easily be seen that the combined hold by the root hairs must be immense. Besides this there is the hold obtained by the mass of roots themselves in mixing and interweaving in the soil. It is this hold the roots have on the soil that prevents the plant being uprooted by the wind; generally the root system breaks before loosening its hold.

The taking in of water is also performed by means of the root hairs. These are in intimate contact with the water which collects around the soil particles, their walls are permeable and the

water is absorbed. From the root hairs this water passes into the cells of the cortex and thence into the wood vessels of the central cylinder. It passes from one vessel to another up the root to the stem, and from the stem to the vessels of the leaves. From the vessels of the leaves it passes into the green cells. There the food salts and part of the water are worked up into organic substances; the excess water is given off in the form of vapor through the breathing pores of the leaves.

This is a brief summary of the course of the water current in the sugar-cane plant and it will be seen that the whole process, so vitally important to the life of the plant, is entirely dependent upon the root hairs and upon new root hairs being formed to replace the old ones, as they lose their absorbing power.

SYMPTOMS OF ROOT DISEASE.

As I have already mentioned, the symptoms of root disease have long been known in these islands, though it is only comparatively recently that they have been recognized as symptoms of a definite disease. I have shown specimens of diseased canes to several plantation managers and nearly all of them are familiar with the appearances, and have been for some time. They are exceedingly characteristic, and once known, the recognition of root disease is easy.

It is noticeable here, as with the root disease in the West Indies, that the symptoms are nearly always much more marked with ratoons than with plant cane. Very often, where the plants have appeared to the ordinary observer to be quite healthy and have given a good crop, the ratoons have shown, after a few months' growth, marked indications of root disease and have been an entire failure.

The general appearance of a cane badly attacked by root disease is shown in Fig. 1, *b.*, while a cane of the same age and variety grown under the same conditions, but only slightly attacked by root disease, is shown side by side at Fig. 1, *a.*, for comparison. These canes were between 3 and 4 months old.

LEAVES.

The leaves being the most conspicuous organ of the plant, it is usually on them that the effects of the disease are first noticed. Instead of dark-green, broad, spreading leaves, these appear narrower and shorter and stand closer together. Normally the leaves remain green for a considerable time before they dry up, so that we get a dozen or more green leaves on a good plant at the same time. A plant affected with root disease shows a very different appearance; the leaves dry up prematurely, they turn yellow, first at the tips and margins, and the yellowing gradually

spreads over the entire blade. Young leaves do not develop so rapidly as in the normal case and even those that are still green do not open out in a normal way, but remain wholly or partially rolled up, and stand erect. This rolling up of the leaves is a phenomenon met with in many grasses (including the sugar-cane) in dry weather; the breathing-pores (stomata), through which water passes out of the leaves, are in this way protected from coming into free contact with the outer air. The rolling thus reduces the amount of water vapour passing out into the air, in connexion with a diminished supply of water from the soil.

The whole appearance of the leaves, in fact, suggests lack of water. The older leaves, and first those parts of them remotest from the stem, dry up and die; young leaves, which give off water freely, develop slowly, while those that do develop roll up and stand upright to reduce their giving off of water.

The same symptoms are met with in canes suffering from drought, but then every cane in the drought-affected area will be affected and moreover the symptoms disappear as soon as the plants are supplied with water; when, on the other hand, the symptoms are due to root disease, in most cases only a limited area will be affected, and other neighboring canes, under the same conditions as regards water supply, will not show the same appearance. Moreover, when root disease is present, the symptoms are more permanent; they do not disappear, although they may be slightly less noticeable, with an increased water supply. Of course, on an irrigated plantation this question will not arise. On non-irrigated plantations, in districts where the water supply is capricious, root disease is often worse during a dry season and there is often confusion as to how much of the drying is due to drought and how much to root disease. In the West Indies this connexion between dry years and root disease is very marked; the same will probably be found to be the case here—certainly it is indicated by the fact that irrigated plantations have not suffered from root disease to the same extent that non-irrigated ones have.

LEAF-SHEATHS AND EYES.

One of the most characteristic symptoms of root disease is seen on examining the sheaths of the lower leaves. Normally, as these die, they dry up and fall away, or at any rate are easily stripped off, leaving the stem clean. In a diseased cane, on the contrary, they become matted very closely together round the

stem, so that it requires some force to remove them. The sheaths are moist and rotten and possess a characteristic musty smell. This matting together extends for a foot or more from the level of the soil.

On examining these matted leaf-sheaths more closely, white thread-like strands may be seen running in and among and through them. These strands are similar to that shown on a young shoot in Fig. 5, and, magnified 42 diameters, in Fig. 7; as shown in Fig. 7 they sometimes broaden out, and sometimes instead of, or proceeding from, definite strands one finds broad, white felt-like plates. These strands and plates are really the mycelium, that is the vegetative part, of the fungus which causes root disease. It does not seem able to grow to any great distance above the ground, and only when sheltered by the matting of the leaf-sheaths which it brings about.

FIG. 5. Lower bud of diseased sugar cane starting into growth. Note the white strands of fungus mycelium spreading out over the lower bud-sheaths. Natural size.

These strands are very similar to those found in the soil (Fig. 6), and are composed of the parallel-running hyphae shown in Fig. 8. The eye frequently grows away from the fungus, which, however, remains alive at the base of the young shoot, and begins to grow upward again as soon as the lower leaf-sheaths begin to lose their vitality.

Another feature of root disease, which, however, it shares with some other cane diseases, is the sprouting of the lower buds or eyes of the stalk. The fungus threads, at first, grow up with the young shoots as shown in Fig. 5. Generally the shoots grow away from the fungus; this, however, remains attached to the lower part and, as the lower sheaths on these shoots begin to die, starts growth again as on the main stalk.

ROOTS AND SOIL.

Stripping away the matted leaf-sheaths, another symptom of root disease is seen in the roots which have started developing from the nodes. In many cases hardly any of them are more than $\frac{1}{4}$ to $\frac{1}{2}$ inch long, while others appear to have had their growth arrested as soon as it started. In other cases some roots may have developed some distance before their growth has been stopped. On a healthy cane, roots taken from a similar spot

would be of all lengths up to several inches. The tips of these stunted roots look unhealthy, they are of a dull dark brown or black color and are flattened. Undeveloped roots often show as dark points in the rind of the cane at the joints.

Obviously the disease is showing here by preventing the growth of the roots, arresting their development, generally, at an early stage. Sometimes these roots are quite covered with the white felt of the mycelium of the root fungus.

Examining the soil about the base of a diseased cane one finds again the mycelium of the root fungus. This is easily seen on breaking off pieces of the soil, and takes the form of white thread-like strands as shown in Fig. 6, quite similar to those met with between the leaf-sheaths. The strands may be seen ramifying and branching, passing sometimes from one dead root to another, sometimes in the soil itself; together they form a branching network all around and among the cane roots.

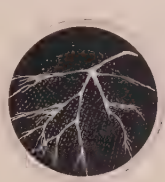

FIG. 6. Infected soil (represented by the black back-ground) with white strands of fungus mycelium, showing how the fungus spreads in the soil. Natural size.

These strands, which occur in great numbers about the bases of diseased canes, are one of the clearest indications of root disease. On breaking the soil from such a locality across, the strands are nearly always plainly visible.

EFFECT ON GROWTH.

A cane stool attacked by root disease usually begins to show its effects when growth has been going on a few months and when the stalk is beginning to form. Later on, a diseased stool presents a very poor appearance, there are only a few stalks, and these are shorter and thinner and drier than in a normal cane. The stool in fact looks starved. Apart from this, the stems show no diseased phenomena.

Another feature of diseased stools is the slight hold they have on the soil. In bad cases a slight pull with one hand is sufficient to uproot a stool; even in less marked cases, the attachment of the plant to the soil is much feebler than that of a healthy cane.

The starved appearance of the stool suggests that the roots are not fulfilling one of their main functions, that of supplying water and food salts. The ease with which the plant is pulled up shows they are not fulfilling the other, that of anchoring the plant in the soil.

In these islands root disease sometimes shows itself very

early in growth. I have seen young shoots, not a foot high, turning yellow, and exhibiting all the signs of root disease. These on examination have been found to be attacked by root fungus. They were, later on, killed off by the disease. The same effect has been noted with the donkelan disease of Java.

EFFECT ON GERMINATION.

More than this, there is evidence to show that the root fungus attacks germinating cuttings and prevents the development of the eyes. Mr. C. F. Eckart, Director of the Division of Agriculture and Chemistry, carried out some experiments in 1904 which tend to show this. The following is his account of the experiments:

'In April, 1904, a stool of Lahaina cane was received from the Waiakea Mill Co. which was badly checked in growth and from which but few roots developed. This was submitted to Mr. R. C. L. Perkins for examination shortly prior to his departure for Australia. Mr. Perkins stated that the roots of the cane were infested with parasitic fungus. It was then determined to carry out the following experiment:

'(1) Two tubs containing 150 lb. each of Experiment Station soil received 4 lb. of soil from around the diseased cane clump. Lahaina cane cuttings, 5 in number, each bearing 3 eyes, were planted, i. e., 30 eyes in all, for the two tubs.

'(2) Two tubs were treated the same as in (1) except that the cane cuttings were soaked for 12 hours in Bordeaux mixture.

'(3) Two tubs were filled with 150 lb. Station soil and untreated Lahaina cuttings were planted as in No. 1.

'The planting in these tests took place April 23, 1904. On July 27, the cane was cut and weighed. The following data were obtained:

'(1) 10 eyes germinated. The largest cane measured from base of stalk to tip of highest leaf 6 feet. The weight of green matter formed was 188 grams; of roots, 22 grams.

'(2) 17 eyes germinated. The largest cane measured 5 feet 6 inches. The weight of green matter formed was 399 grams; of roots, 20 grams.

'(3) 13 eyes germinated. The largest cane measured 7 feet 1½ inches. The weight of green matter formed was 406 grams; of roots, 37 grams.

'In explanation of the poor germination of eyes, even in the

case where uninoculated soil was used, it is necessary to state that all of the tubs were placed on a shady verandah and consequently received the direct rays of the sun only during a small portion of the day.'

Speaking at the Planters' meeting in 1904, Mr. Eckart thus sums up his conclusions:

'A short time ago we got some soil from down in the Hilo district where root disease is prevalent and where it is necessary to replace the Lahaina with more healthy and thrifty varieties. We inoculated, in tubs, some of the station soil with a little of the soil from Waiakea that was obtained from around Mr. Kennedy's plantation. Wherever we inoculated the station soil with the soil from Waiakea, there was a difference in the germination of the cane cuttings from where we had not inoculated the soil. That would indicate that our disease is different from the West Indian disease.'

In the West Indies *Marasmius sacchari*, the root fungus of those islands, has never been proved to have any effect on germination. In Java, however, the same fungus, *Marasmius sacchari*, is known to destroy cane cuttings in the nursery beds, in which the canes are placed before planting out, besides attacking mature canes. So the fact that the Hawaiian root fungus prevents germination is no proof of its being different from the root fungus of Java and the West Indies. The following translation from Wakker and Went's book on sugar-cane diseases in Java shows this point clearly:

'It is peculiar that this disease appears in two different ways, but at the same time of the year; I deem it desirable first to describe the symptoms in both cases separately and will then try to explain the supposed relation.

'I would like to add now that the symptoms present themselves in the first place in the nurseries, which are not too young, and in the second place in mature fields during or immediately before harvesting. The latter symptoms are the most serious.

'The following symptoms are observed whenever nurseries are affected:

'First the number of sprouting buds is always much smaller than otherwise. As the non-sprouting of buds can also be caused by a number of other circumstances, for instance, age, damage by insects, etc., it cannot be classed as a characteristic symptom of the disease.

'Second, and this is much more typical, we see that the already sprouted buds begin to show a weak appearance just by the time of transplanting, that is nearly three weeks after the nurseries were started.

'The most conspicuous feature is, that first the younger leaves, sometimes also the older leaves, start to die from the top and soon dry up, assuming a pale straw-like color, without spots or an edge of a strikingly different color.

'Such buds do not die but lead a poor existence and can even be transplanted.

'Between the extremes mentioned many intermediate forms are found, as might be expected. Especially I observed, here and there, buds of which only the bud-sheaths had grown, without leaves having formed.

'Generally speaking, the superficially observable symptoms resemble somewhat the damage done by white ants. Upon investigation of the parts under the surface it appears that if it is really root disease, the easily recognized inroads of above mentioned insects are not to be seen.

'Instead of cuttings, of which not much is left besides the shell with here and there a piece of the joint, they are apparently normal, and only a single bundle of mycelial threads, snow-

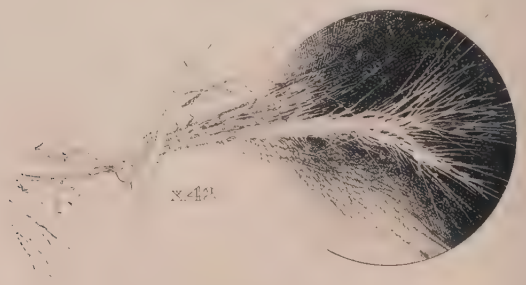

FIG. 7. One of the strands shown in Fig. 5, magnified 42 diameters, to show the method of branching and spreading out of the strands and indicating the arrangement of the hyphae. (The black back-ground toward the top of the illustration is necessary in order to show up the fine white strands of the mycelium and its mode of branching.)

white and glossy, like silk, extending over the seed, branching off here and there and losing itself in the soil, arouses suspicion.

'If one cuts the seed lengthwise, it often presents a hollow space inside, filled with the threads mentioned or shows red spots on the joints. This color is not essential, I never did see

red spots like those of "Rood Snot" or vascular bundles partly colored red in the joints as in the case of "Sereh."

'The root formation is always more or less defective and the ends of the cuttings are rotten.

'As shown in the above the characteristics of the disease are not very prominent and I consider this the cause why the disease, although it can do much damage, was discovered only very recently.'

Of course Mr. Eckart's experiments though extremely suggestive are not perfectly conclusive. The Waiakea soil used for inoculation *may* have contained the spores of other fungi, notably of the pine-apple disease of cuttings, and these *may* have been the cause of the poor germination in the inoculated soil. In the absence of a plant pathologist it does not appear that any post-mortem examination of the cuttings was made. It is proposed to repeat the experiment later, using sterilized soil and pure cultures of the root fungus.

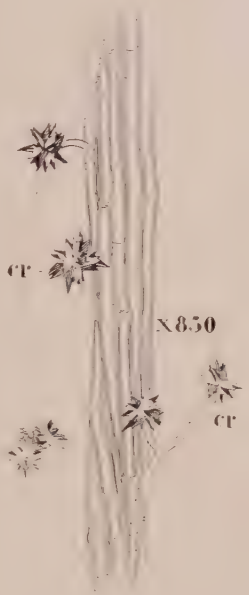

FIG. 8. Some of the fungus mycelium from a strand similar to that shown in Figs. 5 and 7. Note the branched, septate hyphae, their (for the most part) parallel arrangement, and the interweaving. The septa are simple cross walls and no clamp connexions are shown. Notice also the star-shaped clusters of crystals of calcium oxalate (*cr.*) borne on hyphae which stand away from the general course of the strand. Besides these clusters, single crystals are sometimes found in great numbers studding the walls of the ordinary hyphae. Crystals of calcium oxalate are common in fungi and are probably a by-product of metabolism. Magnified 850 diameters.

MICROSCOPIC EXAMINATION OF THE ROOT FUNGUS.

If one of the white strands of the root fungus, either from the soil or from the leaf-sheaths, be examined under a microscope we get the appearance shown in Figs. 7 and 8. The strand is seen to be composed of a number of very fine threads; these are the hyphae of the fungus, which together form the mycelium. In the strands the hyphae are seen to be running mostly in the same direction, along the long axis of the thread, but rather irregularly and interbranching and interweaving enough to make the strand a compact whole.

When the mycelium spreads out into the form of a plate, it is

accomplished by the hyphae ceasing to run parallel to one another but branching and interweaving in all directions.

The hyphae vary somewhat in size, those shown in figures 8 and 11, for instance, measure about 1-1,000 millimetre (1-25,000 of an inch) in diameter. Seen under a high power, the hyphae are divided by cross walls (septa) into segments, as are those of all the higher fungi. Most of the septa are of the ordinary form, being simple cross walls (Figs. 8 and 11), but occasionally one meets with a joint as shown in Fig. 9. This is known as a clamp connexion; it is formed by the growing out of a process, just on one side of a septum, which curves round to the wall on the other side of the septum and fuses there; the separating walls break down and a side connexion is formed between the two adjoining segments of the hypha. These clamp connexions are mentioned because, as will be seen later, they are of some systematic importance. The highest group of fungi are the Basidiomycetes, characterized by the production of toad-stools; to this group belongs the root fungus of the West Indies and Java. Clamp connexions are to be found in the hyphae of nearly all Basidiomycetes and hardly ever outside this group.

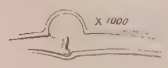

FIG. 9. Part of a hypha of the root fungus from a strand similar to that shown in Fig. 7. Note the structure of a clamp connexion and compare with the structure of ordinary joints, as shown in Fig. 8. Magnified 1000 diameters.

Clamp connexions are not easily found in the mycelium of root fungus; that they do occur is additional proof that the fungus is a Basidiomycete.

A characteristic feature of the hyphae of the root fungus is the presence in their walls of crystals of calcium oxalate (Fig. 8. *cr.*). The crystals are usually produced as shown, in a star-shaped manner, on the swollen tips of short hyphae. Sometimes, in addition, large numbers of single crystals are found embedded in the walls of the ordinary hyphae.

MICROSCOPIC EXAMINATION OF DISEASED ROOTS.

Longitudinal sections of diseased roots were prepared and examined microscopically; the roots selected were those described above as stunted in growth and with a discolored tip. A section of one of these, from Lahaina cane, is shown in Fig. 10 magnified 100 diameters. It may be mentioned that the section figured here was taken from a root growing from a point 9 or 10 inches above the soil.

At once it is seen that the tip differs from that of a normal root (compare Figs. 3 and 10). The root cap is evidently much reduced and looks unhealthy, the cells are flatter and show no signs of being replenished from the growing point.

The growing point itself also show evidences of disease, it also is flattened out and does not appear to be actively forming

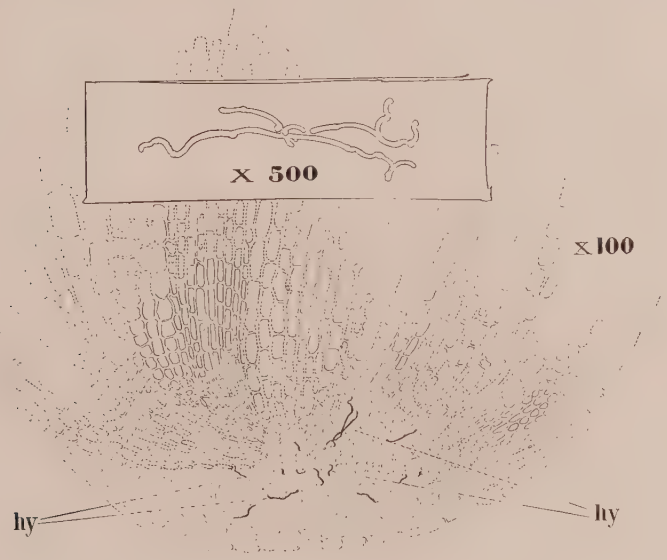

FIG. 10. Longitudinal section of root tip attacked by root fungus. Note the small fungus hyphae (*hy.*) in the tissues of the root cap and passing from there into the meristem. Compare this section with that shown in Fig. 3; notice the smaller, flattened-out root cap and the less active meristem cells; later on the tissues of the root cap and meristem are completely destroyed. Branches commonly arise quite close to the diseased root tip; these in turn are attacked by the fungus. Magnified 100 diameters.

FIG. 11. A few of the fungus hyphae from Fig. 10, magnified 500 diameters. The hyphae are septate, the septa being of the usual type. Compare with Fig. 8.

These hyphae branch and wind in all directions in the diseased tissues; many of them are cut straight across, and only the cut ends are seen in section; owing to the small size of the hyphae these ends could not be shown in Fig. 10.

new cells. This is especially noticeable in preparations stained to show the cell contents. In a normal growing point, the cells are full of living matter, which is found actively dividing and giving rise to new cells. In a diseased tip, the living matter is less in amount and evidently active division is ceasing.

Careful examination with a high magnification shows the cause of the trouble. A number of very delicate fungus hyphae (Fig 10. *hy.*) are found penetrating in and among the dead and dying cells. The hyphae, as seen by a comparison of Figures 8 and 11, are similar, in their general characteristics, to those of the white mycelium outside. They appear to penetrate the root cap first and to pass from this into the actively dividing cells of the growing point. In both places they branch in all directions growing into both living and dead cells. They absorb the food supply of the cells and when these are killed, live on their dead remains; in this way all the living cells of the growing point are soon killed and the dead tissues invaded in all directions by the fungus mycelium. It is now easily understood why the root tips seen from the outside appear discolored.

The root tip shown in Figure 10 is only in an early stage of this disease; later on, as described above, the root cap and growing point are entirely destroyed and flattened out and the fungus then spreads to the young cells of the cortex; it does not however, while the root is alive, seem to penetrate far into the central cylinder.

Often the root seems to make an effort to overcome the parasite by branching quite close up to the dying growing point. It produces, in fact, another growing point to replace that destroyed. Root branches arise from the central cylinder and have to push their way through the cortex. With root disease, usually before the branch has emerged, its growing point is attacked and destroyed as was that of the parent root.

Later, after the root has been killed, the fungus spreads to all parts of the root and promotes its decay. In this it is aided by other fungi and by bacteria which are present in the soil. But for all practical purposes, the direct damage done by the root fungus is confined to one spot, the growing point of the root.

EFFECT OF FUNGUS ON NUTRITION AND GROWTH.

The primary damage done by the root fungus being now understood, it remains to be seen what effect this has on the general growth and nutrition of the sugar-cane plant.

As has already been pointed out, it is at the growing point alone that the formation of new tissues takes place. The root hairs, which are the absorbing organs of the plant in the soil,

are short lived, and, normally, are continually being replaced by new ones from cells produced at the growing point. When the activity of the latter ceases, this supply is cut off, so that in a short time the root has no functional root hairs; consequently the activity of that root in absorbing water is destroyed. In other cases, the growth of the root may be stopped before its root hairs develop.

As old sugar-cane roots reach their full development and then die, in the normal course of events, their place is taken by new roots developed from underground parts of the stem. When the root fungus is present and destroys the young roots as soon as they begin to grow, it is not long before the consequent reduction in the water-absorbing power of the root system begins to make itself felt. The water, with its contained food salts, is absorbed in gradually decreasing quantities; consequently less and less of these substances find their way into the leaves, there to be elaborated up into sugars, proteids, etc.

Apart from this, the plant keeps on trying to produce new roots to replace those destroyed by the fungus and so is continually drawing on the supplies of food elaborated in the leaves, while at the same time, as the supplies of raw materials from the roots are continually diminishing, the plant becomes less able to provide the supplies for their development.

EFFECT ON ABSORPTION AND GIVING OFF OF WATER.

It can now be seen why the first effect of root disease is seen in the rolling up and yellowing of the leaves. The leaves are, at this stage, in a normal state of activity and so giving off water vapour freely; the roots on the other hand are sending up less water than usual; the state of affairs is the same as that met with in times of drought and the plant responds to it in the usual way, that is, by rolling its leaves and so shutting off the free passage of the outer air over the breathing pores, so lessening evaporation. In this way a balance is struck between absorption and evaporation of water. The rolled up condition of the leaves becomes permanent, but the loss of absorptive power is a progressive one. In the next stage, the leaves do not get enough water to keep their tissues alive and so the ends and margins—the parts remotest from the water supply—begin to dry up and turn yellow.

EFFECT ON OTHER FOOD SUPPLIES.

The rolled up condition of the leaves is in itself not favorable to the nutrition of the cane. It is well known that green plants take in part of their raw food from the air in the form of the gas carbon dioxide. This, together with the other raw materials from the soil, is worked up through a complicated series of changes to sugars, proteids and other elaborated food materials. These changes take place in the leaves in sunlight and the resulting elaborated foods are conveyed to wherever growth may be going on or are stored in the stem for future use.

Now it is evident that any mechanism which lessens the amount of water vapor passing out of the leaves into the air, by checking the free interchange of gases, must at the same time lessen the amount of gases taken into the leaves from the air. So, the rolling of the leaves as a result of diminished water supply, has for one of its results the lessening of the food supply taken in from the air; this again results in a lessening of the sugars and proteids available for growth, and so root development, among other things, receives another check.

STARVATION OF SUGAR-CANE PLANT.

The whole process detailed above affords an excellent example of the way in which each part of the mechanism of the plant works in with every other part. Throw one part out of order and the whole mechanism is checked.

The starved appearance of a badly attacked stool of canes is now easily understood; it has its supply of raw food materials cut off at both ends and continually getting less, while the leaves are unable to supply elaborated food for the production of new absorbing organs.

The ease with which the plant is uprooted is, of course, due to the prevention of any development of roots, the anchoring organs of the plant.

It is now seen how every symptom of root disease can be traced back to the effect of the one primary damage done by the root fungus, the destruction of the growing point.

RELATIONS BETWEEN SUGAR-CANE AND FUNGUS.

A sugar-cane does not inevitably succumb to the attack of the root fungus in the manner I have described. It is a matter of experience that canes, showing symptoms of the disease, do

sometimes grow their whole course without showing much material injury and may give a good yield; this is especially the case with plant canes growing under favorable conditions. Canes may even be noticeably injured by root disease and, if conditions change for the better, may throw it off and apparently entirely recover.

This is explained by the fact that the root fungus is not a strong parasite; it cannot enter, indiscriminately, any root tip and destroy the growing point, but a certain degree of weakness, a certain loss of vigor and vitality in the growing point, is necessary, before it can develop its parasitic powers and push its attack home.

On the other hand the sugar-cane, as may have been gathered, possesses considerable powers of resistance to the root fungus. When one root is destroyed another is developed to take its place and this can go on until the plant has exhausted its reserve of food materials. In fact, unless a shoot is attacked at a very early stage, it is rare to find one entirely killed by root disease.

The whole struggle between the root fungus and its host plant turns upon external factors, the chief of these being temperature, water supply, mechanical condition and fertility of the soil. If the conditions are such as to promote healthy, vigorous root development, the fungus is outgrown and its attack, at least for the time, thrown off. If, on the other hand, the temperature is too low, the soil contains too much or too little water, or is too closely packed, then root development receives a check and the parasite is able to overcome the resistance. Thus also, as conditions vary in an infected area, first checking, then favoring, root development, so in proportion does the progress of the disease vary.

Of course if the disease has already proceeded to such an extent as materially to reduce the plant's food reserve and check its growth, before conditions change to favour the host, recovery can only be partial and is often not noticeable.

RATOONS AND ROOT DISEASE.

The foregoing considerations will explain why it is that ratoon canes suffer more severely than plants from root disease. When plants start their growth, all the conditions are such as to favour the cane; the soil has recently been thoroughly cultivated and is in a good state of tilth suitable for root development. Moreover the cultivation by admitting air and sunlight has destroyed

a certain amount of fungus mycelium in the soil; the temperature, if the cuttings are planted early, on the mauka lands, is high and continues so long enough to give the plants a good start; in dry districts special attention is paid to conditions of rainfall, so that in this respect, also, the plant cane gets as favorable conditions as possible.

The ratoon, even when perfectly healthy, is never so vigorous as the plant cane. Growth is always noticeably slower, both with the root and shoot system, so that root fungus, which entirely depends on the vigor of its host, has a better chance. Again, cultivation cannot be so thorough for ratoons as it is for plants; at best it can only result in a stirring and aeration of the surface soil; consequently the lower soil will be much closer and harder than when thoroughly cultivated, which again will prove a check on root development and so aid the fungus in its attack. Another point is that the mycelium of the fungus, during the growth of the plants, is allowed to grow unchecked and so increases largely in the soil and especially about the base of the stool where it is not disturbed by cultivation; the result of this is that as soon as the ratoon roots begin to develop the fungus is already in a favourable position to attack them. The conditions, then, for ratoons as compared with those for plant canes are, on the one hand, less favourable for the cane and, on the other hand, more favourable for the fungus. In the West Indies the difference is even more marked, as the climatic conditions, also, are far less favourable for the growth of ratoons, which start their growth in the dry season.

IRRIGATED AND NON-IRRIGATED PLANTATIONS.

The same considerations explain why it is that irrigated plantations suffer less from root disease than the non-irrigated. The water supply is always abundant and, so, one of the most important conditions is always favourable to the cane; when the attack begins the unaffected roots have always a plentiful supply of water to draw on and consequently the general nutrition of the plant does not suffer so soon, as the cane is in a better position to replace the roots destroyed by the parasite.

MODE OF LIFE AND SPREAD OF THE ROOT FUNGUS.

Fungi may be divided up into groups according to the way in which they obtain their food supply. Some of them can only

take it from living hosts and cannot live on dead organic matter; these are the strict parasites. Others, again, can only take their food from dead animals and plants and cannot enter living tissues to obtain nourishment from them; these are the strict saprophytes. A third group can live and grow indefinitely, taking their food from dead matter, but can also under certain conditions enter the tissues of living plants and take their food from these; this group comprises the facultative parasites. To the third group belongs the root fungus; it lives and grows on the dead trash at the base of the cane; it grows on dead roots and stems below ground and can go on indefinitely living and spreading in the soil so long as there is sufficient dead organic matter present. It is this that makes it a difficult pest to get rid of. When a plant cane throws off its attack and sends out vigorous roots that cannot be destroyed, the fungus is not killed off, it lives on at the base of the cane, on dead leaf-sheaths, dead roots, etc., and so maintains its existence as a saprophyte, until conditions change and it is able to assert its parasitic nature. This generally happens, for instance, when the cane is ratooned.

There are two main sources of infection to be noted in considering the spread of root disease: first, diseased cuttings and, second, the soil. I have already shown that the leaf-sheaths on the lower part of the stem are infected with the fungus mycelium, not only so, but also that the developing roots some distance above the soil are also infected. If a cutting from this part of an attacked cane be planted, even though the leaves be stripped off, the fungus is planted too, and under the favourable conditions of darkness and moisture commences its growth with the cane. It can now spread, from the infected cutting as a center, through the soil, living on the organic matter there, passing from one cane to another, until a whole group of canes is attacked.

In many cases the soil is infected before the canes are planted; the fungus mycelium lives on any dead plant remains there, but especially on the dead cane stumps, if left over from last year's crop. In such a case the fungus mycelium in growing through the soil soon comes across the young cane plants; if the roots be growing feebly they will be attacked and destroyed; if the young roots be vigorous the fungus will grow on any old roots or other dead parts below the soil, will pass from these to the lower leaf-sheaths as these begin to dry up, and so establish itself around the base of the plant. In this way a whole field of

cane may easily be attacked. The struggle begins between host and parasite with varying results as conditions favour one or the other.

TREATMENT.

A consideration of the life history of the root fungus and the relation between it and its host plant leads on naturally to the methods of dealing with the disease. It cannot be expected that the disease can be entirely eradicated, but, with a knowledge gained from a study of the fungus, it is possible to suggest treatment that will materially reduce the amount of disease and keep the fungus well in check. The treatment naturally falls under two heads—first, that which will weaken or destroy the fungus in the soil or on the canes; second, that which will encourage the growth of the cane and increase its vigour so that it will be better able to withstand the attack of the fungus.

CULTIVATION.

The cultivation of the soil is a treatment that works both ways. By loosening and generally improving the condition of the soil, with the consequent aeration, this is rendered better adapted to the healthy and vigorous growth of the root system of the cane. On the other hand as the soil is stirred up, the fungus mycelium, which would otherwise have been sheltered in the earth, becomes exposed to the action of air and sunlight, and in this way becomes weakened and a large proportion of it killed. The result is that the chances of the root systems of the next canes to be planted in the soil becoming attacked are greatly reduced and this apart from their own more healthy condition which renders them again less liable to be injured by the attack.

Ratoons, in these islands, receive a certain amount of cultivation, chiefly surface cultivation between the rows. This, by admitting light and air to some extent, checks the growth of the fungus. In wet districts, deeper tillage would probably be of even greater value in dealing with root disease. In dry districts, anything more than surface cultivation, to a depth of a few inches, is likely to do more harm than good; by a deeper cultivation, the capillarity of the soil is reduced and the root system disturbed, neither of which consequences would be of so much importance in a wet or irrigated district. Surface cultivation by breaking up the capillarity of the top layers of the soil,

of course, conserves the moisture in the deeper layers. This, at any rate, is the result of the experiments with root disease in the West Indies.

DISTANCE OF PLANTING.

A suggestion made by Mr. C. F. Eckart may prove of great value in dealing with root disease. This is, briefly, the wider planting of cane on infected land. In this way, by having the rows, say, six feet apart instead of five, more light and air will be admitted between the rows and around the bases of the canes. The healthy effect of light and air, both as regards the growth of the cane and the destruction of the fungus mycelium, has already been laid stress upon. At any rate the suggestion is well worth a trial on infected land. It may be pointed out that wider planting does not necessarily mean smaller crops; there will be fewer plants, but these may be larger individuals.

ISOLATION OF DISEASED CANES.

Sometimes root disease appears in small patches in a field the rest of which is unaffected. If these areas be located in time, it is possible to isolate them and prevent the disease spreading any further through the soil in the manner previously described. This is accomplished by digging a trench around the infected spot, of greater depth than that to which the cane roots descend, that is about a foot to eighteen inches. It must be remembered that the fungus mycelium will have spread further than the area in which the disease is noticeable; the trench should, therefore, be made to include one or two rows of cane that are apparently healthy. The soil dug out should be thrown inside the trench, as throwing it outside this would be infecting healthy soil with fungus mycelium. In cases where this treatment is practicable it is a very good method for confining the disease to a limited area.

SELECTION OF CUTTINGS.

The use of diseased cuttings has already been mentioned as one of the ways in which the fungus is spread and carried to previously uninfected localities. It is therefore necessary to use the greatest care not to plant cuttings infected with root disease. It would be obviously wrong to plant cuttings from the lower part

of the stem with the matted leaf-sheaths and fungus mycelium on them. Even if the sheaths be stripped off, I have shown that the fungus is still present in the developing roots. In dealing with fungoid diseases it is always advisable to leave a fairly wide margin for safety; the mycelium is always found to spread beyond the parts where it is externally visible. Consequently it will be far safer not to use any cuttings from plants that show the external symptoms of root disease. If this be not possible cuttings should at least be taken from a part of the cane some distance above where the matting of the leaf-sheaths is visible. If diseased canes are used for propagation, not only is there a risk of directly infecting the land, but, what is perhaps of greater importance, there is also risk of breeding up a race of canes susceptible to root disease. This is in exact opposition to all good agricultural practice, which is to breed exclusively from healthy stock and so increase its resistant powers to disease.

DISINFECTION OF CUTTINGS.

Mr. Eckart's experiments, detailed above, tend to show that the ill effects of root fungus on germination may be remedied by the treatment of cuttings with Bordeaux mixture before planting. This treatment requires further trial on a larger scale and on infected land; this cannot be carried out at the Experiment Station, but the experiment must be tried on a plantation which has some infected land. The best method would be to run two or three rows of treated cuttings right across an infected field, the remainder of which should be planted with untreated cuttings. Full details of the plans of the necessary experiments cannot be entered into here, but all possible advice and assistance will be given by this Division to any plantation manager who is willing to undertake the tests.

The treatment of infected soil with fungicides is not only a very difficult and large undertaking, but has proved in the West Indies, to be ineffectual in dealing with root disease of cane.

RATOONS.

The question whether plant canes affected with root disease should be ratooned is not a simple one and must be decided largely by local conditions. If external conditions are favourable, a ratoon crop may withstand and grow away from the disease to a great extent. On irrigated plantations, for instance,

where the water supply is constant and abundant it may be advisable to ratoon. It is only under exceptional conditions that this is advisable in other cases; the ratoons are sure to suffer more than the first crop canes and, if conditions are at all unfavourable to growth, the fungus, established in the soil and around the cane stools, will have every chance to ruin the crop.

If, then the plant canes suffer at all noticeably from root disease, they should never be ratooned. If the attack on the plants is only slight the question must be settled by local conditions. From a purely pathological point of view it is never wise to ratoon an infected cane; as during the growth of the ratoons the soil will be more and more thoroughly infested with the fungus mycelium and so will be in a worse condition for the succeeding crop. The economic point of view is necessarily more complex.

DESTRUCTION OF DISEASED MATERIAL.

One of the surest ways of increasing the amount of fungus in the soil, is that of leaving in it the remains of canes which are infected with the mycelium. It is every bit as important in combatting plant diseases to destroy infected material, as it is in dealing with human diseases.

If the old cane stumps are left to decay in the soil, the fungus mycelium will continue to live on them indefinitely and will be just in the right condition and position to attack any cane roots in the neighborhood. The stumps in fact give the fungus a base from which it can spread to living canes.

In ploughing over diseased fields it will be well to make a special point of having the shares guided so that they turn to the surface nearly all the old stools; if no special attention be paid to this many of the stools will be covered up and left in the soil, there to propagate the disease.

The infected stools should be thoroughly destroyed. When practicable the very best method of doing this is to burn them. In other cases it may be less expensive to remove the stools to land that will not be planted in cane, mix them with quick lime, cover them with soil, and allow them to decay where there will be no chance of their infecting other canes. The same treatment should be applied to any other infected material, the matted leaf-sheaths, for instance, at the base of the cane.

LIME.

When the cane stumps are removed, there will still be left a certain amount of fungus mycelium in the soil. This can be destroyed to a great extent by the use of lime. The lime should, if possible, be unslaked, as in that state it has far greater fungicidal powers. It should be applied before ploughing and along the rows where the cane has been growing, as it is there that the fungus mycelium will be most luxuriant. The quantity to be applied must depend upon local conditions and the extent of the disease; probably never less than 1,000 lb. per acre should be used for this purpose.

STRIPPING.

The removal of the matted lower leaf-sheaths has been found in some cases to lessen the damage done by root disease. Taking away these infected coverings from the developing roots at the base of the cane must necessarily diminish the chances of these roots being infected as they emerge. Not only so but the admission of air to the lower parts of the cane will tend to improve their health, apart from the question of infection. The stripping should be commenced as soon as the matting of the sheaths is noticed and should be repeated as soon as it becomes evident again. Of course the stripped trash should be destroyed in the same way as other infected material and not be used to spread the disease to other cane.

RESTING INFECTED LAND.

Land that has become so badly infested with root disease that it is impossible to raise a fair crop even of plant canes upon it can often be improved by resting it from cane cultivation. During this period, which should be quite extended if it is hoped to starve out the root fungus, the land should not be neglected or allowed to become overgrown with weeds. In fact one of the chief advantages of resting, is that it gives the opportunity for a very thorough cultivation of the soil. The land should be ploughed as often as can be managed, the furrows being run in different lines each time, so that fresh lots of fungus mycelium are turned up and exposed to the destructive action of the sun and air. A good dressing of quick-lime applied before ploughing would materially aid in destroying the fungus.

While the land is resting, of course, fresh supplies of plant food are being rendered available for the uses of the cane. There is, on the other hand, danger, in districts with an excessive rainfall, of food salts being washed out of the soil, which will thus be in a worse condition for growth at the end of the fallow than it was before. To avoid this, green dressings of some leguminous plant might be grown and ploughed in; this, of course, will add organic matter, of which some of the mauka soils already have too much. There is a need here of some remunerative crop, which could be grown on badly infected lands for a year or two in rotation with the sugar-cane.

DRAINAGE.

Any condition of the soil which tends to hinder free root development favours root disease. Thus both excessive drought and excessive moisture are favouring conditions for the disease. Excessive drought on a non-irrigated plantation cannot very well be remedied, but the effects of excessive water can be lessened by paying attention to the drainage. This applies especially where the soil is at all retentive of moisture or where the soil is thin with a close subsoil. In such localities it would be worth trial whether the growth would not be improved by planting the cane on the ridges instead of in the furrows. This, I understand is the practice adopted in some of the parts of British Guiana, where the soil is liable to contain excessive moisture.

RESISTANT VARIETIES.

It seems most probable that the abandonment of first Lahaina and then Rose Bamboo canes, on certain plantations, has been largely due to the extent which these varieties are attacked by root disease. At present the Yellow Caledonia variety appears to be markedly resistant and to flourish on lands where the other two varieties do not thrive. Yellow Caledonia itself is not immune to the disease. I have seen specimens of it showing unmistakable symptoms, although they had not suffered to any great extent.

The Yellow Caledonia possesses features which may explain its powers of resistance. It is, in the first place, a more vigorously growing cane, and particularly it has a more vigorous root system; it may thus be capable of outgrowing an attack to which the other varieties would succumb. It is also a more upright cane and parts with its trash more readily, both points of impor-

tance in preventing the fungus from creeping up the stems. Whether this explains the whole case or whether this variety has any more remote powers of resistance cannot be definitely decided until our knowledge of the internal economy of the cane is more exact and extensive.

It will not pay to rely entirely upon the resistant powers of Yellow Caledonia and neglect other methods of dealing with the fungus. If this be done and the fungus be allowed to continue unchecked in the soil, it may in time adapt itself as thoroughly to the constitution of the Yellow Caledonia as it has already to that of the Lahaina variety. In particular, care should be taken not to allow the Yellow Caledonia to deteriorate by planting diseased cuttings.

Some of the new seedling varieties now being raised at the Experiment Station, it is hoped, may show a high degree of resistance. This is a point that cannot be entirely settled at the Experiment Station; the tests for resistant varieties must be field tests carried out, when possible, on infected land. Every plantation manager who is carrying out tests with new varieties should make it a special point to note the comparative resistance of each to root disease (also to rind and other diseases) and include it in his report on the variety.

It is not to be supposed that every remedial measure suggested will be applicable to every plantation in these islands. Where such a variety of conditions exists the only thing that can be done is to suggest as many lines of treatment as possible and to leave each plantation manager to pick out those which, from his local knowledge, he considers applicable to his own particular conditions.

IDENTITY OF THE ROOT FUNGUS.

Specimens of diseased cane were sent in September, 1904, to the Bureau of Plant Industry of the U. S. Department of Agriculture at Washington where they were examined by Mr. Rorer with the object of having the disease identified. A reply was received in March, 1905; the canes had received very careful examination, cultures had been made of the fungus and a microscope examination made of the mycelium. The conclusion arrived at was that the cause of the trouble was other than *Marasmius sacchari*. One of the chief reasons given for this conclusion was that no clamp connexions had been found on any material, either in the mycelium on the canes sent, or in that obtained in cultures; while the clamp connexions had been specially noted in the mycelium of *Marasmius*

sacchari both in Java and the West Indies; hence the stress laid upon clamp connexions in an earlier part of this paper. Another reason was that no fruiting bodies had been found.

As already mentioned clamp connexions have been found in material similar to that sent to Washington and one of them is shown in Fig. 9. This seems to remove one of the differences emphasized. It was not an easy matter to find the clamp connexions, they appear very sparsely and it was only after many days' careful searching, that an indubitable one was found. Neither Wakker nor Howard, in describing the disease due to *Marasmius sacchari*, mentions the scarcity of clamp connexions.

FIG. 12. Toad-stool of *Marasmius sacchari*, the root fungus of Java and the West Indies.

Note the stalk (springing from a diseased root) which bears the cap. On the under side of the cap note the gills on which the spores are produced. From a photograph of a specimen which had shed its spores and was partly dried up. Natural size.

These toad-stools are best seen in the early morning, as they dry up when the sun gets on them. They grow quite close to the base of the cane and are easily overlooked. No toad-stools have been found belonging to the Hawaiian root fungus.

The other point, the absence of fructifications, by which alone a fungus can be recognized, is not so much a difference as a want of proof of identity. It must be remembered, moreover, that the Washington trials were made in a temperate climate in the winter, when conditions would hardly favour the fructification of a tropical fungus.

Personally, I am strongly of the opinion that the two diseases are identical and I have had the advantage of studying them in the field in the West Indies and in these islands. The matter can only be settled by obtaining the fructifications of the Hawaiian fungus, getting pure cultures from the spores and carrying out infection experiments.

It is certainly remarkable that no toad-stools have been found and I should be very glad if any one would forward to this Division, any small toad-stools which are found growing on or near diseased canes. The appearance of those of *Marasmius sacchari* is shown in Fig. 12, drawn from a West Indian specimen. They are small, not more than an inch across and often smaller, the colour is a dirty white. They are composed of an umbrella-shaped (sometimes flat) cap, supported in the middle by a thin stalk. The toad-stools are extremely delicate and soon dry up, so that the best time to find them is in the

early morning. They usually are found near the base of the stem, springing either from dead roots or the matted trash. Taking all these points into consideration, they are not likely to be found without careful search. Specimens of toad-stools sent in for examination are best preserved in water containing 2 per cent of formaldehyde (5 parts of commercial formaldehyde to 95 parts of water); if this is not available they may be preserved in wood alcohol or other spirit; dry specimens wrapped in paper and carefully packed should also be sent.

Every effort is being made in the laboratory of this Division, to obtain the fruiting bodies of the root fungus. Hitherto, these have had no result. It is hoped to publish the results of culture and infection experiments as a separate bulletin when these are complete.

In conclusion, I have to express my thanks to Dr. N. A. Cobb, Director of this Division, and to Mr. C. F. Eckart, Director of the Division of Agriculture and Chemistry, both of whom have read this bulletin in MS., for many suggestions and much advice. The illustrations are the work of Mr. E. M. Grosse, of this Division.

SUMMARY.

Root disease is the most important fungoid disease of sugar-cane in the Hawaiian Islands. It is responsible for the abandonment of Lahaina and Rose Bamboo canes in certain localities. Its most marked effects are seen on ratoons.

The first symptoms of root disease are like those of drought. The leaves stand upright, roll up, turn yellow, and gradually become very dry; the leaf-system is much reduced. The lower leaf-sheaths become matted together and to the base of the stem. A white fungus mycelium is found among them. In Hawaii root disease is also noticed to affect germination.

The root fungus attacks the growing point of roots, so preventing their further development. As this continues, the water supply from the soil is reduced, this brings about secondary effects on nutrition, which react again upon root development. Finally the nutrition of the cane suffers severely.

The sugar-cane, growing naturally, possesses considerable powers of resistance to root fungus and is able to outgrow an attack.

Root fungus is essentially a soil fungus. It is able to live as a saprophyte on dead organic matter in the soil, and especially about the bases of the cane stools.

Treatment for root disease consists in, first, planting resistant varieties, as the Yellow Caledonia, the utmost care being taken to secure healthy seed. Cultivation and liming the soil tend to destroy the fungus there and are also favourable to the vigorous development of cane roots. Ratooning is, generally, not advisable. The destruction of diseased material should be as thorough as is consistent with economy. It is sometimes necessary to throw land out of cane cultivation on account of this disease; a remunerative rotation crop would be of great value here.

BIBLIOGRAPHY.

Cobb: *The Inspection and Disinfection of Cane Cuttings*: Bulletin No. 1. H. S. P. A. Experiment Station, Division of Veg. Pathology and Physiology. Honolulu, 1905.

Earle: 'Report on Observations in Porto Rico:' Annual Report of the Office of Experiment Stations, 1903. Washington, 1903.

Howard: 'A Root Disease of Sugar-Cane in Barbados.' *International Sugar Journal.* Vol. V. p. 267.

Kruger: *Das Zuckerrohr und seine Kultur*: Magdeburg, 1889.

Lewton-Brain: *Lectures on the Diseases of the Sugar-Cane*: Pamphlet No. 29, Barbados, 1904.

Lewton-Brain: 'Review of the Principal Fungoid Diseases of the Sugar-Cane.' *West Indian Bulletin*, Vol. VI, p. 33.

Wakker and Went: *De Ziekten van het Suikerriet op Java*: Leiden, 1898.

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